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**OPERATIONAL CHARACTERISTICS OF A TRANSLATION SCREEN GRID  
BEAM DEFLECTION SYSTEM FOR A 5-CM KAUFMAN THRUSTER**

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# OPERATIONAL CHARACTERISTICS OF A TRANSLATION SCREEN GRID BEAM DEFLECTION SYSTEM FOR A 5-CM KAUFMAN THRUSTER

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## SUMMARY

The recent development of the vectorable beam ion thruster enhances its potential use for satellite station keeping and attitude control. One type of beam deflection system is the translational screen grid.

Measurements of beam deflection angle with respect to spring positioning power and accelerator impingement current as a function of deflection angle were made on a 5-cm diameter system fabricated under Contract NAS3-14058 and results compared with similar measurements made by Hughes Research Laboratories. The results were in good agreement. Response time measurements on the translational grid beam deflection system showed that the time for the maximum deflection angle analyzed ( $+16.4^{\circ}$  to  $-16.4^{\circ}$ ) could be reduced by a factor of nine by increasing the heating power applied to the positioning spring from 4 to 16 watts. At 14 watts the response time for maximum deflection was about 1 minute.

## INTRODUCTION

Increasing emphasis on orbiting spacecraft for Earth resources studies, meteorology, navigation, and communications is planned in the 1970's. Many of these satellites will have stringent, long duration station keeping and attitude control requirements. As satellite lifetime increases, the high specific impulse ion thruster becomes an increasingly competitive alternative to cold gas and chemical type thrusters. The Lewis Research Center is working on a 5-cm Kaufman thruster with the durability (lifetime) and specific impulse to meet this satellite need. The Lewis 5-cm thruster

program (both inhouse and contract) has been described in Refs. 1 and 2.

Recent development of ion thrusters with beam deflection capability enhances their usefulness, since they can perform both station keeping and attitude control functions. Hughes Research Laboratories personnel investigated several techniques for varying the thrust direction of a mercury bombardment ion thruster under Contract NAS3-14058. The results of this contract are described in Refs. 3 and 4. Two beam deflection systems looked particularly promising — the electrostatic dual-grid system and the translational screen grid system. The electrostatic dual grid system can deflect the beam around two orthogonal axes by electrostatic biasing of the accelerator grid elements. The translational screen grid system deflects the beam by purposely misaligning the screen so that the beam is attracted more toward one side of the accelerator hole. A follow-on contract, NAS3-15385, is in progress to further develop the 5-cm diameter electrostatic system. One of the electrostatic vector grid systems from the first contract effort has been run for 1000 hours on a Lewis built 5-cm diameter Kaufman thruster (ref. 5). The present report describes a 5-cm diameter translational screen grid system, also from the first contract effort. Beam deflection by translationally offsetting the screen grid with respect to the accelerator grid has been analyzed by several researchers (refs. 6 to 9).

The translational screen grid system is shown in Fig. 1. The screen grid is supported by four flexible columns which maintain the screen to accelerator spacing but allow transverse motion. The actuator system is composed of eight cobalt-nickel alloy springs. The springs are mounted in opposing pairs along two mutually perpendicular axes (fig. 1). The screen grid is translated by joule heating of the springs. Grid deflection is proportional to the change in spring temperature. Reference 4 contains a discussion of the relevant equations and preliminary measurements of elongation as a function of change in temperature,  $\Delta T$ .

Response time of the translational grid as a function of power dissipated in the springs was determined and the zero power cooling characteristics of the springs were measured. Tests were performed at Lewis to measure grid displacement and beam deflection angle with respect to spring positioning

power. The accelerator impingement current as a function of deflection angle was also measured. These results are compared with similar measurements made by Hughes Research Laboratories.

## APPARATUS AND PROCEDURES

### Beam Deflection Experiments

The deflection system shown in Fig. 1 was mounted on a 5-cm thruster (fig. 2) for the beam deflection tests. The thruster is described in Ref. 1. A hollow cathode neutralizer of the enclosed keeper type (ref. 2) was used for all tests. The tests were performed in a 4.5 meter long, 1.5 meter diameter vacuum facility (ref. 10). During the experiments the tank pressure was maintained near  $1 \times 10^{-6}$  torr.

Ion beam deflection angles were determined using the beam analysis equipment depicted in Fig. 3 and described in detail in Refs. 4 and 11. A molybdenum button rake system was used to obtain current density profile measurements. Fifteen 1.27-cm diameter molybdenum discs were spaced along the 51 cm rake. The rake was located 58 cm downstream of the accelerator grid and traversed 40 cm across the ion beam. The currents measured at the molybdenum buttons were processed on a digital computer and the results stored on magnetic tape. Further computer processing yielded microfilm plots showing two dimensional contour maps of equal current density, coordinates of the centroid of the distribution and an integrated value of beam current. Comparing the centroids of the undeflected and deflected modes yields the average angle through which the ions have been displaced.

Deflection angles and accelerator current values were measured for various levels of spring power at a beam current of 25 milliamperes and total voltage of 2000 volts. The accelerator currents were also measured for various values of total accelerating voltage. In all cases the positive and negative accelerating voltages were of equal magnitude.

## Response Time Experiments

The apparatus used to measure the response time of the grid translation system is shown, Fig. 4. The control circuits alternately switch the power supplies on and off so that the grid translates back and forth between micrometer end stops. The grid was mounted in a 44-cm diameter bell jar which is part of the vacuum facility described in Ref. 10. The bell jar was kept at a pressure of  $1 \times 10^{-6}$  torr throughout the experiment.

The power supplies and associated electronic circuitry is such that when started, power supply No. 1 is turned on heating the springs which drives the grid to the right. Power supply No. 1 remains on until the grid makes electrical contact with the right micrometer stop. Then the switching circuit turns off power supply No. 1 and turns on power supply No. 2. Now the other set of springs is heated causing the grid to translate to the left. When the grid reaches the left micrometer stop the switching circuit again switches the power supplies and the grid translates back to the right. During each heating cycle the current and voltage applied to the springs are recorded on a strip chart recorder. The voltage was also measured with a digital voltmeter.

The translation characteristics were measured at seven different power levels. At each power level the translation times between micrometer settings (which correspond to seven angular displacements) were measured. The relationship between beam deflection angle and screen grid translation was found to be  $3.10 \times 10^{-3}$  cm per angular degree. In the following discussion the translation times are given for beam deflection angles rather than linear displacements of the screen grid. At each micrometer setting the translation time was measured five times in both directions. The first cycle in each group was used to allow the system to come to thermal equilibrium. The other four periods were averaged and used to plot response time versus angular displacements. The cool-down characteristics of the grid system were also measured. The measuring procedure was to heat the

springs to either  $\pm 16.4^\circ$  deflection and then measure the time necessary for the springs to cool to 12.3, 8.2, 4.1, and  $0^\circ$ . These measurements were made at several power levels.

## RESULTS AND DISCUSSION

### Beam Deflection Experiments

A number of spring power levels were set and the resulting deflection angles were determined from beam probe analysis. The results shown in Fig. 5 are for thermal equilibrium conditions. The solid curves represent data taken by the contractor (ref. 4) and the data points are from the present experiment. Good agreement in test data was obtained. An ion beam deflection of ten degrees was obtained with 1.2 watts of spring power. All data were taken at a beam current of 25 milliamperes and total voltage of 2000 volts. Figure 6 shows the accelerator drain current versus deflection angle. Better than  $10^\circ$  deflection angles are obtained without an appreciable rise in accelerator current.

In addition to the deflection tests, the accelerator currents at zero deflection were measured as a function of total accelerating voltage for various levels of accelerator grid voltage. Results shown in Fig. 7 indicate that a total accelerating voltage of 1800 volts is necessary to minimize the accelerator current. The accelerator current is less than 1 percent of the beam current at this minimum.

### Response Time Experiments

Tests were conducted with increased spring power to determine what decrease in response time might be achieved. The experimental results are plotted in Figs. 8 and 9. Figure 8 is a graph of translation times from  $-16.4^\circ$  to  $+16.4^\circ$  for seven different power levels. Figure 9 is the same graph for translation times going from  $16.4^\circ$  to  $-16.4^\circ$ . In both figures the

curves are monotonically increasing with an increasing slope. Comparing the 3.88 watt curve with the 16.0 watt curve of both figures shows the response time for a  $-16.4^{\circ}$  to  $16.4^{\circ}$  displacement was decreased by a factor of more than nine. A point of decreasing effectiveness occurs at about 12.0 watts. At high powers the additional decrease in response time is small in comparison to the increase in power. A power level of 14.0 watts would allow full range deflection ( $16.4^{\circ}$  to  $-16.4^{\circ}$ ) in either direction in approximately one minute. The response times were not exactly repeatable, variations of 3 percent were commonly observed. The variations seemed to be random, so that precision vectoring would require a feedback control loop. The results for two sets of springs are qualitatively similar, but sufficiently different to imply that a preflight calibration of springs and feedback circuitry in the flight vectoring system would be necessary.

Figure 10 is a plot of the natural cooling characteristics of the translational vector grid. The curves were very similar at the different power levels tested. The slopes of the cooling curves are very large near the zero position. It takes about two and a half to three times longer to cool from  $4.1^{\circ}$  to  $0^{\circ}$  than to cool from  $16.4^{\circ}$  to  $4.1^{\circ}$  of beam deflection.

### CONCLUDING REMARKS

Response time measurements on the translational screen grid system showed that the response time for the maximum beam deflection selected ( $\pm 16.4^{\circ}$  to  $-16.4^{\circ}$ ) could be reduced by a factor of nine by increasing the spring power from 4 to 16 watts. The point of decreased effectiveness was at about 12 watts. At 14 watts the response time for maximum deflection was about 1 minute. This significant reduction in response time could enhance the usefulness of the translational screen grid. The natural cooling time of the springs are long (16 to 32 min.). In a flight application it would be more desirable to return the system to zero by powering the opposing set of springs.

Measurements of beam deflection angle with respect to input spring power and accelerator current as a function of deflection angle compared favorably with measurements made by the Hughes Research Laboratories on the same accelerator system prior to delivery to Lewis Research Center. An ion beam deflection of  $10^0$  was obtained with a constant spring heating power of 1.2 watts.

#### REFERENCES

1. Reader, Paul D.; Nakanishi, Shigeo; Lathem, Walter C.; and Banks, Bruce A.: A Submillipound Mercury Electron Bombardment Thruster. *J. Spacecraft Rockets*, vol. 7, no. 11, Nov. 1970, pp. 1287-1292.
2. Nakanishi, S.; Lathem, W. C.; Banks, B. A.; and Weigand, A. J.: Status of a Five-Centimeter-Diameter Ion Thruster Technology Program. Paper 71-690, AIAA, June 1971.
3. Collett, C. R.; King, H. J.; and Schnelker, D. E.: Vectoring of the Beam from Ion Bombardment Thrusters. Paper 71-691, AIAA, June 1971.
4. King, H. J.; Collett, C. R.; and Schnelker, D. E.: Thrust Vectoring Systems. Part I - 5 cm Systems. Hughes Research Labs. (NASA CR-72877), 1971.
5. Lathem, Walter C.: 1000-Hour Test of a Dual Grid, Electrostatic Beam Deflection Accelerator System on a 5-Centimeter-Diameter Kaufman Thruster. NASA TM X-67907, 1971.
6. Lathem, Walter C.: Effects of Electrode Misalignments in Kaufman Thrusters. *J. Spacecraft Rockets*, vol. 5, no. 6, June 1968, pp. 735-737.
7. Lathem, Walter C.; and Adam, Wallace B.: Theoretical Analysis of a Grid-Translation Beam Deflection System for a 30-cm Diameter Kaufman Thruster. NASA TM X-67911, 1971.

8. Fosnight, V. V.; Dillon, T. R.; and Sohl, G.: Thrust Vectoring of Multiaperture Cesium Electron Bombardment Ion Engines. *J. Spacecraft Rockets*, vol. 7, no. 3, Mar. 1970, pp. 266-270.
9. Seliger, R. L.; Nudd, G. R.; Brewer, G. R.; and Amboss, K.: Analysis of the Expected Thrust Misalignment of Kaufman Thrusters. *J. Spacecraft Rockets*, vol. 7, no. 4, Apr. 1970, pp. 422-428.
10. Keller, Thomas A.: NASA Electric Rocket Test Facilities. *Transactions of the Seventh National Symposium on Vacuum Technology*. C. Robert Meissner, ed., Pergamon Press, 1961, pp. 161-167.
11. Kerslake, William R.: Accelerator Grid Tests on an Electron-Bombardment Ion Rocket. NASA TN D-1168, 1962.

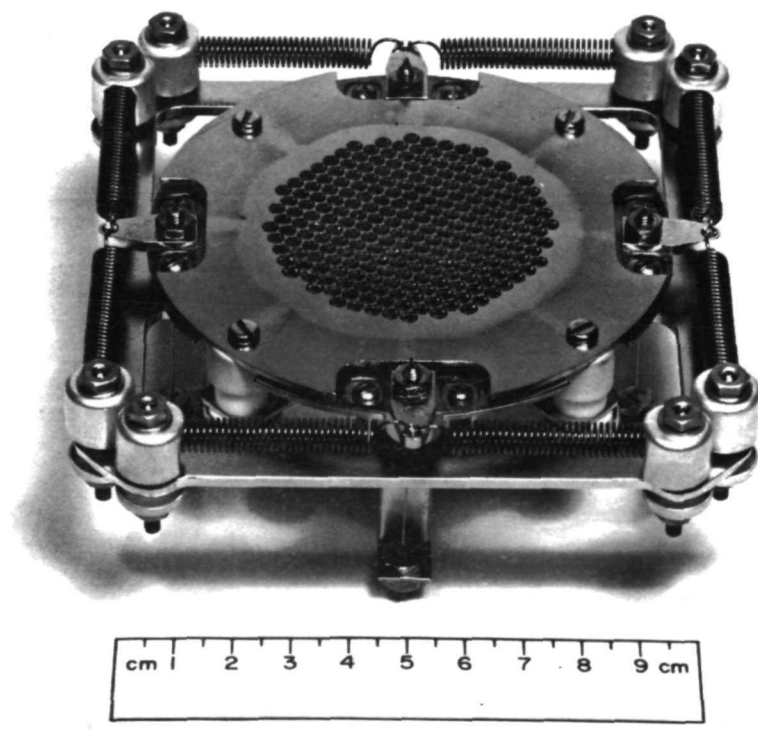


Figure 1.- Thermomechanical 5-cm vectorable grid. (Contract NAS 3-14058, Hughes Research Lab.)

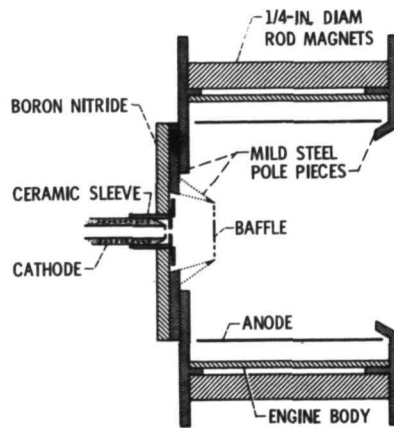


Figure 2 -Cross section of 5-cm diameter thruster discharge chamber without accelerator system.

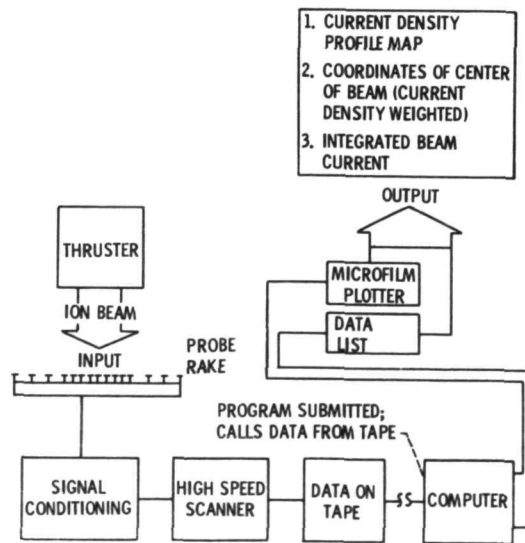


Figure 3. -Block diagram of system used to analyze the ion beam.

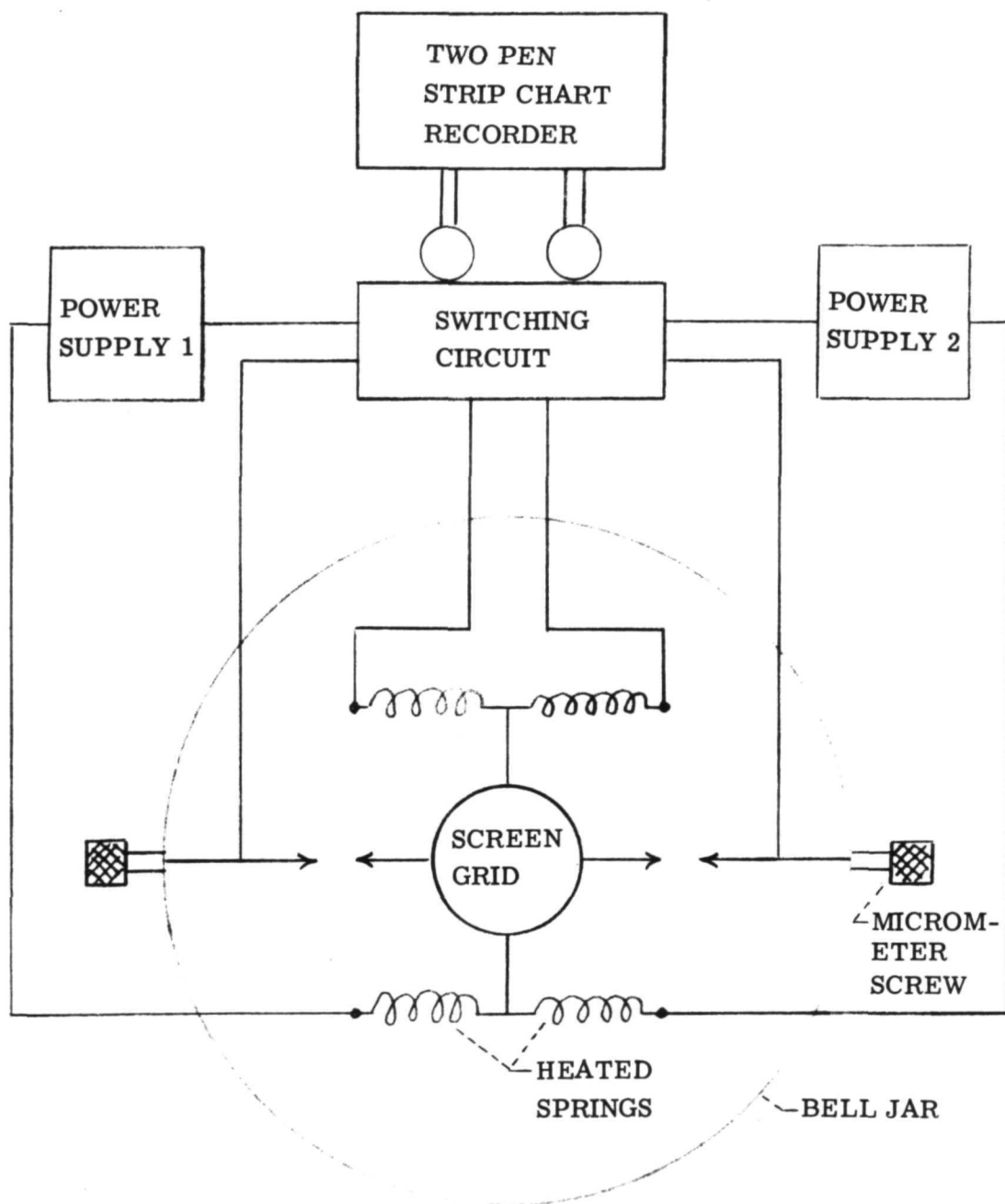


Figure 4. - Diagram of response time test apparatus.

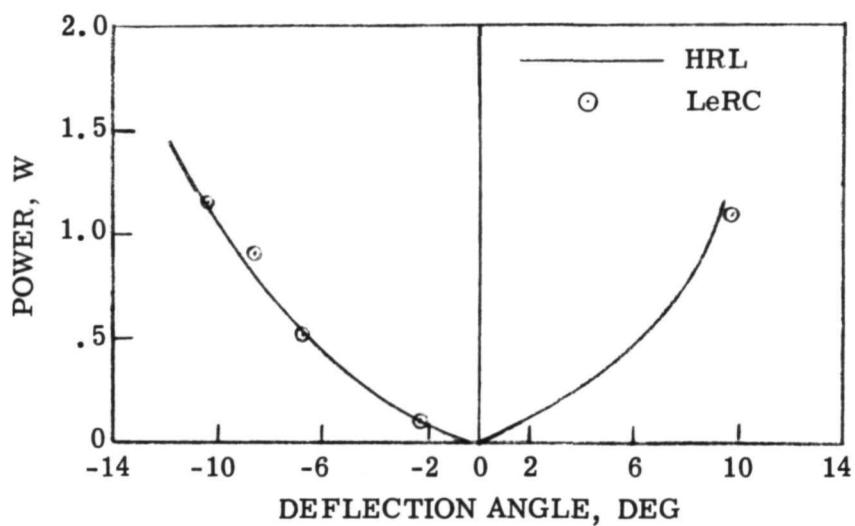


Figure 5. - Beam deflection angle versus spring heating power. (Beam current 25 mA.)

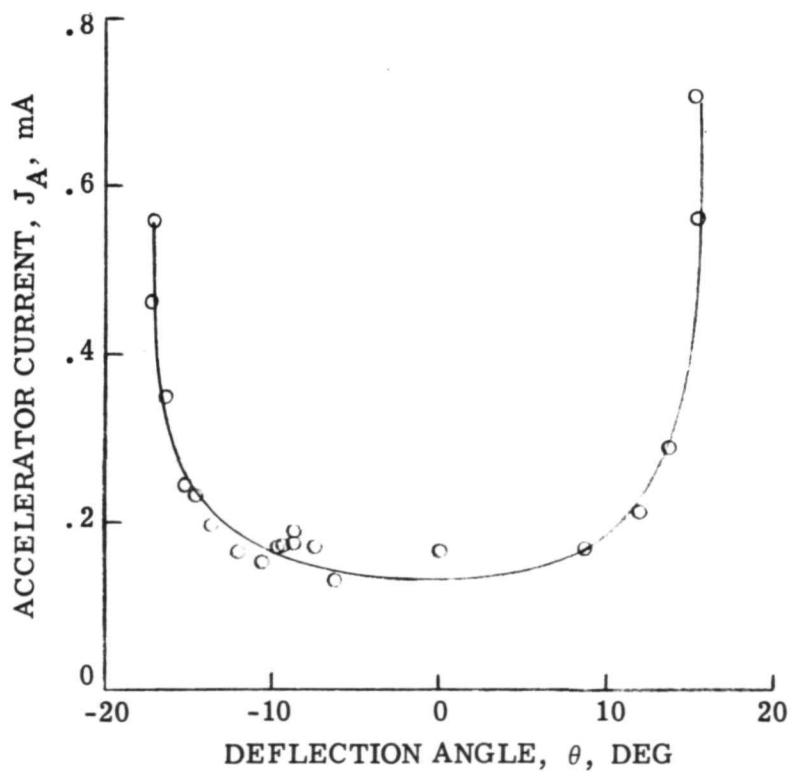


Figure 6. - Accelerator drain current versus deflection angle (total voltage - 2000 volts, beam current - 25 mA).

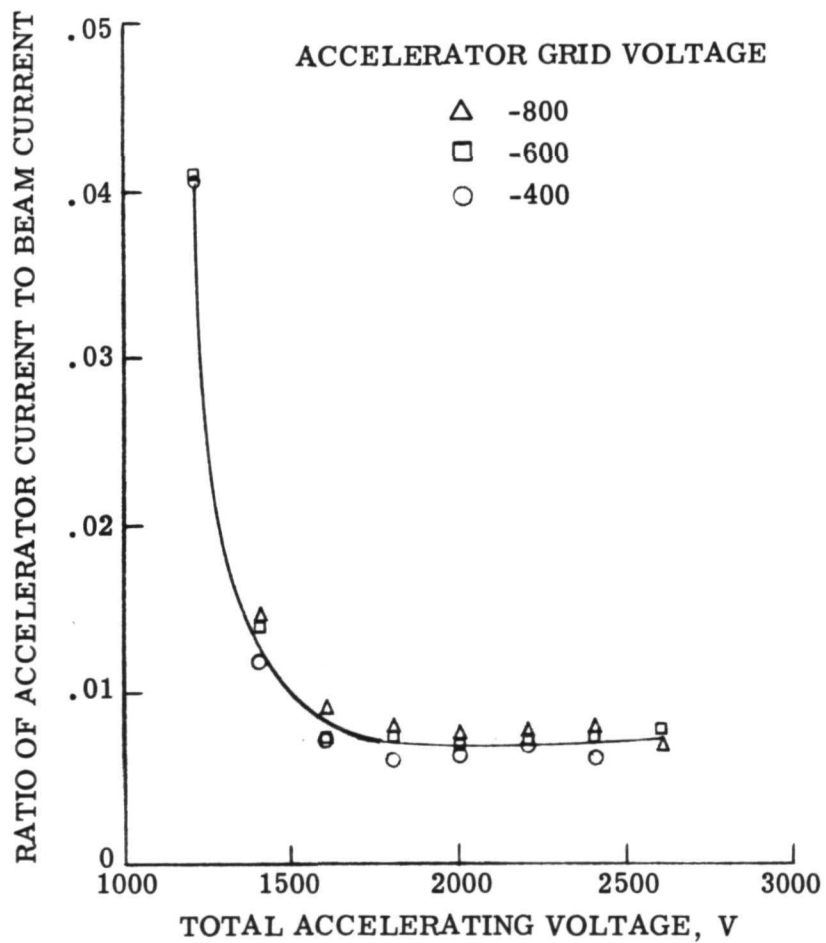


Figure 7. - Ratio of accelerator current to beam current versus total accelerating voltage for various accelerator voltages. (Undelected 25 mA beam.)

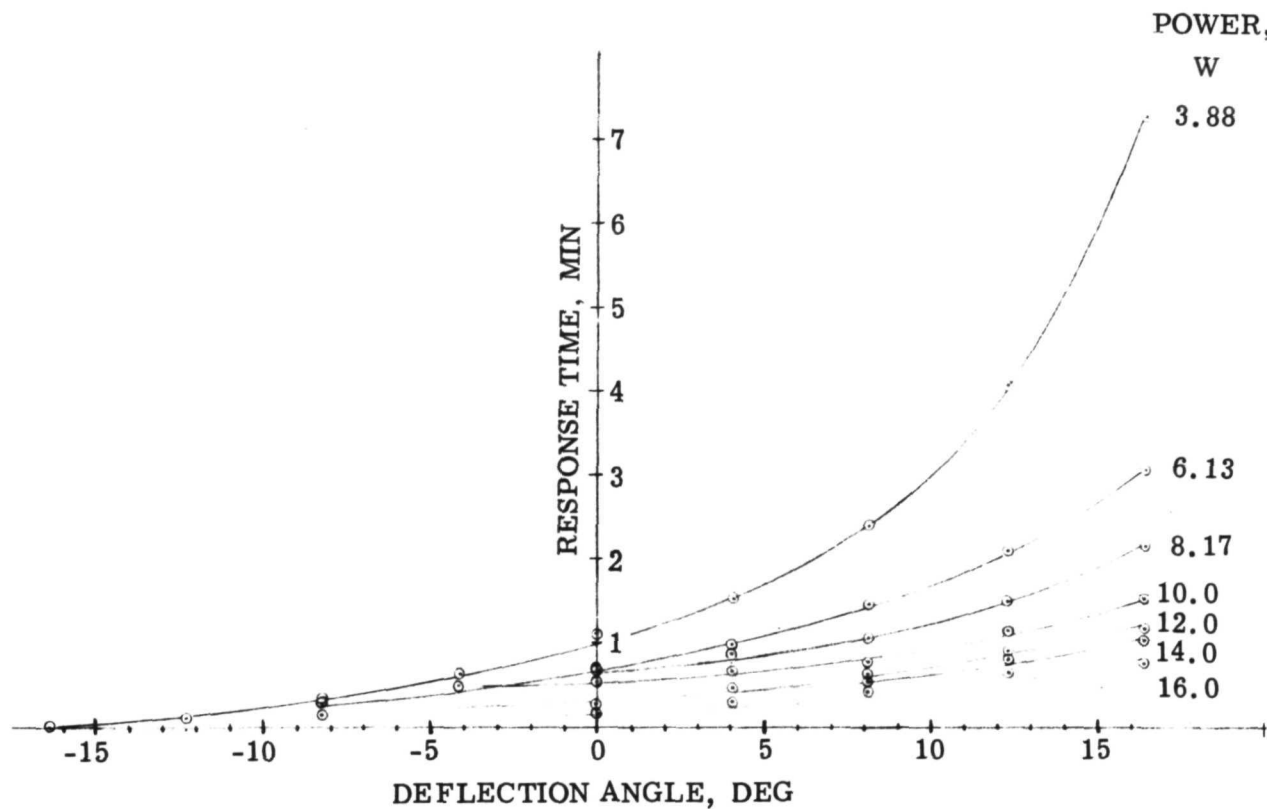


Figure 8. - Translational vector grid response time starting from  $-16.4^{\circ}$  for various spring heating powers.

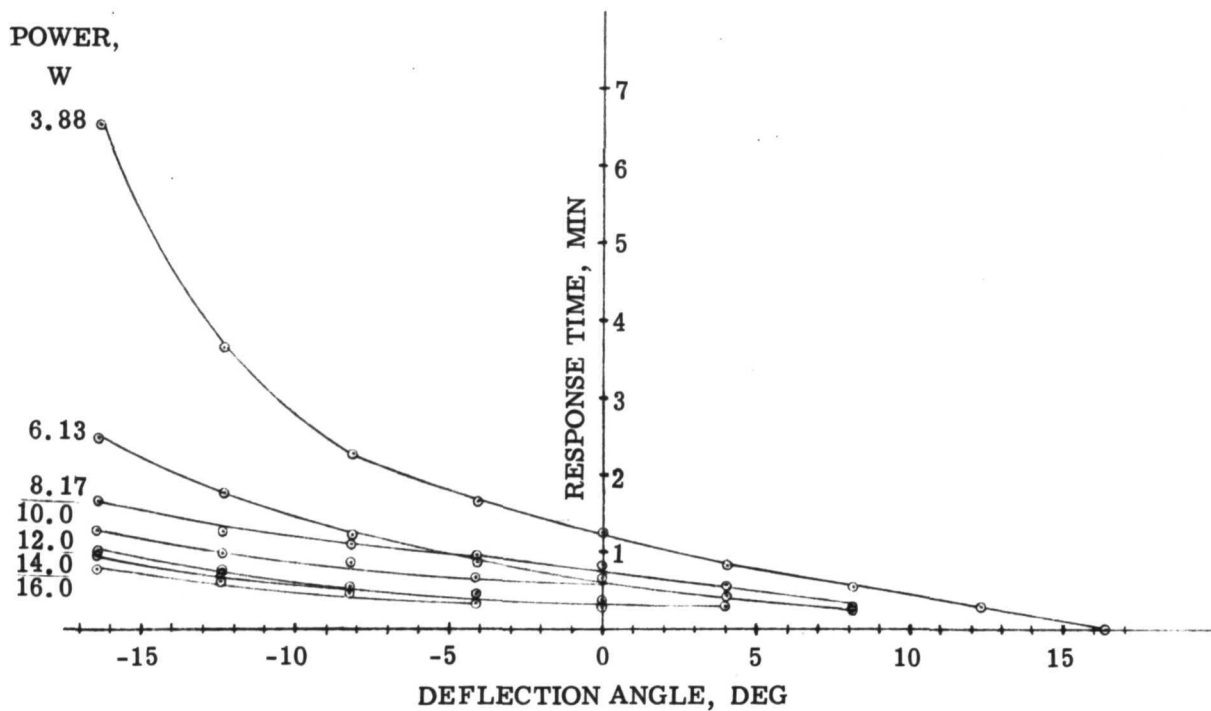


Figure 9. - Translational vector grid response time starting from  $+16.4^\circ$  for various spring heating powers.

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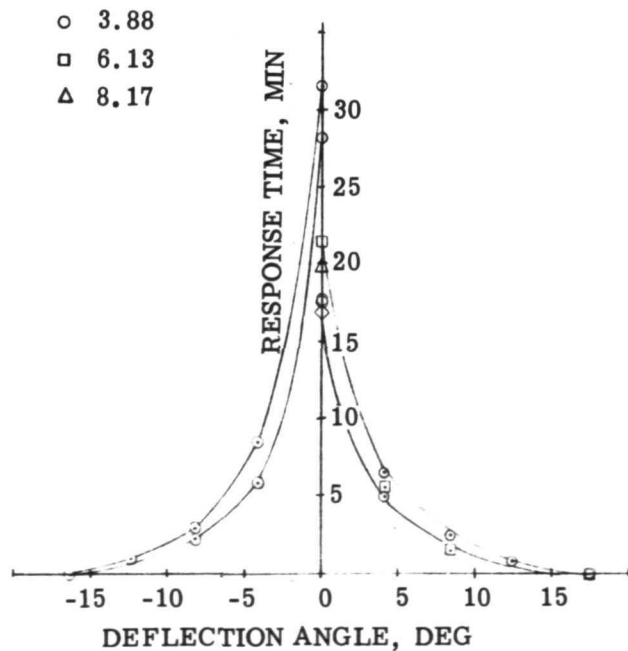


Figure 10. - Natural cooling characteristics of a translational vector grid.